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Some Effects of Atmospheric Temperature

Variations on Performance of the Supersonic Transport

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INTRODUCTION

The supersonic transport will be an extremely complex air vehicle compared to present subsonic jet airliners, due to the wide range of speeds involved and the attendant altitude variations required to achieve maximum efficiency. For this reason, as well as to satisfy the economic and safety requirements for the supersonic transport, careful study must be given all factors having a bearing on operation of the aircraft. Hence, the importance of the various natural phenomena to be encountered, such as wind, rain and ice, ozone and atmospheric temperature, must be established. The purpose of this paper will be to consider, in particular, the effects of variations in atmospheric temperature on the design and on the performance of the Mach 3 supersonic transport.

The first section of the paper describes the procedure used in determining the effects of atmospheric temperature on performance. Following this a brief introduction into the effects of altitude and

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atmospheric temperature on some of the aircraft performance parameters will be shown. The next portion is devoted to a discussion of two important airplane design parameters as affected by variations in atmospheric temperature. Each phase of a typical mission profile then will be considered in detail for a given airplane with respect to standard and hot day conditions. The final section illustrates several operational problems that would result from elevated temperatures occurring along the flight profile.

PERFORMANCE ANALYSIS

In order to determine the losses or gains in performance of the supersonic transport as a result of atmospheric temperature variations ~~from standard~~, it is important to consider the entire mission and not just the area where the temperature change occurs. This is due to the fact that each portion of the flight has a definite effect on the remaining part of the mission. For example, a loss in performance during the climb and acceleration phase, where about one-third of the trip fuel normally is consumed, produces changes in performance during cruise as a result of the altered airplane cruise weight and range. To obtain a realistic analysis, various atmospheric temperature schedules were assumed along a given mission profile and the performance of a typical supersonic transport configuration flying this mission was determined using a digital computer program.

The configuration used for this study was a delta wing and canard type designed for cruise at a Mach number of 3 with four turbofan engines in separate wing mounted pods. The aerodynamic data used [redacted] as inputs to the performance program ~~was~~ were obtained through a series of wind-tunnel tests conducted at Ames Research Center. However, it should be pointed out that many of the problems discussed herein are also of concern for other configurations. The flight range considered was 3200 nautical miles. The take-off gross weight was held constant and the relation between payload capability and fuel consumed was used as a measure of performance. Figure 1 shows the 2 PSF maximum ground overpressure climb profile which was used as an input to the performance program for all cases analyzed. This profile indicates the minimum altitude that can be flown at a given supersonic Mach number in order to avoid ground overpressures greater than 2 PSF and it is a function of the aircraft weight and geometry. After taking off the aircraft was assumed to climb and accelerate to 7500 feet where it would level off and accelerate ~~at~~ to a Mach number of .9 . It was then assumed to climb at a constant Mach number to about 25,000 feet where it would begin to accelerate once again and follow the 2 PSF boundary to a Mach number of 3. The lower portion of the profile is dictated by noise considerations and the efficiency of climbing at the highest possible Mach number, although it was not developed by a comprehensive analysis. It should be pointed out that changes to the profile in this area have very little effect on the overall performance. An increase in altitude of the overpressure boundary in the transonic region, however, can cause a considerable loss in performance because of the rapid reduction in engine thrust. Upon reaching Mach 3, the aircraft was assumed to climb to the desired cruise altitude which must and would be higher than the 1.5 PSF ground overpressure limit for this airplane as indicated in figure 1. The two types of Mach 3 cruise profiles used in this paper were a constant altitude and an optimum or Breguet. A mathematical expression defining the cruise range capability of an airplane was first developed by Breguet and may be written as $\left(V \frac{L/D}{SFC}\right) \ln \left(\frac{Wi}{Wf}\right)$ where V is flight velocity, L/D the lift to drag ratio, SFC the engine specific fuel consumption, and Wi and Wf the weight of the airplane at the beginning and end of cruise, respectively. The first term represents the aerodynamic efficiency, $V \frac{L}{D}$, and the propulsive efficiency, 1/SFC. The so called Breguet cruise is one for maximum range wherein the first term of the equation is maximized and which results in a climbing cruise as will be shown later. Before considering the results of the performance analysis it may be helpful to ~~explain~~ examine briefly the effects of increasing altitude and atmospheric temperature on some of the more important parameters used in calculating aircraft performance.

EFFECTS OF INCREASED ALTITUDE AND ATMOSPHERIC TEMPERATURE ON PERFORMANCE PARAMETERS

While this paper is mainly concerned with atmospheric temperature effects on performance, it is desirable to have an understanding of altitude effects as well because the two are involved in both the climb and in a Breguet cruise. In climb, a change in temperature will affect the engine thrust and this in turn will affect that the altitude above which the airplane has insufficient thrust-drag margin for acceleration through transonic and low supersonic speeds. In cruise, a change in temperature will result in a change in altitude required for maximum aerodynamic efficiency. Figure 2 is included to show the effects of ~~increased~~ changes in altitude and atmospheric temperature on the various performance parameters for the assumed airplane during cruise. Both the cruise Mach number of 3 and the aircraft weight are held constant while varying ~~increasing~~ separately the altitude and temperature. Figure 2a shows the effect of variations in ~~increasing~~ cruise altitude on a standard day, and figure 2b shows the result of variations in ~~increasing~~ atmospheric temperature above standard for a constant altitude. It should be pointed out that both graphs in the figure are plotted to the same vertical scales and that the drag and thrust curves are in pounds.

Referring to the solid curves in figure 2a ~~Looking at 2a and ignoring the dotted curves for the present~~, it is seen that the velocity (V) is constant for the altitude range shown because a constant Mach number is assumed and the speed of sound is constant in this altitude range. The drag (D) falls off as the altitude is increased ~~to about 73,000 feet~~ due to a decrease in dynamic pressure. ~~and then begins to rise~~ However, ~~because~~ the aircraft angle of attack is continuously increased to maintain the required lift. This results in an increase in drag which becomes stronger than the former effect at an altitude of about 73000 feet for this case. As was previously stated, the thrust (T) normally falls off with an increase in altitude for a given Mach number and throttle setting. However, to maintain a cruise condition of Mach 3 the thrust must equal the drag and this requires an increase in throttle setting with an increase in cruise altitude as the drag begins to increase. The small difference in the thrust and drag curves of figure 2 is due to the fact that the aircraft is at a finite angle of attack and a small component of the engine thrust is acting in the lift direction. The specific fuel consumption (SFC) is an indication of the engine efficiency and it represents the pounds of fuel used per hour per pound of thrust produced. As is shown for the cruise condition, the SFC increases with an increase in altitude. This, coupled with an increase in thrust required results in an increased engine fuel flow rate. The aircraft aerodynamic efficiency factor or lift to drag ratio (L/D) goes up as the altitude is increased to about 72,000 feet and then begins to fall off. Because the weight and thus the lift is constant for all the altitudes shown, the L/D value is dependent mainly on the drag and thus it peaks close to the altitude where the drag is a minimum. The difference shown is due to the drag of the engine air induction system which has not been included in the lift-to-drag ratio for this analysis. The dashed curves of L/D and SFC are shown for the same aircraft at a lighter weight due to fuel consumption during cruise. From this it can be seen why an optimum or Breguet cruise, that is flying the maximum value of V x L/D/$_{SFC}$, results in a climbing flight as previously stated. As the weight is reduced the maximum L/D occurs at a higher altitude. Also for the lighter weight the SFC is reduced and the amount of this reduction is greater at the higher altitudes. This lower SFC value is a result of a decrease in drag and thus thrust for the reduced weight, although the latter two values are not shown in the figure. Therefore in order to fly an optimum cruise the airplane ~~will~~ should continuously seek the maximum value of L/D divided by SFC, resulting in a climbing flight as the weight is reduced and the velocity held constant. For this airplane a Breguet cruise results in a climbing flight from about 68,000 to 77,000 feet during a 3200 nautical mile mission.[1] Although the effects of altitude during cruise have been discussed herein, the climb and accelerate portion of the mission is similar. The main difference is that during climb, the thrust is not equal to the drag and for a given throttle setting, say maximum power, the thrust and fuel flow rate fall off with an increase in altitude.

1. An optimum or Breguet cruise was considered in this study, but it may be that in the actual operational phase of the supersonic transport this type of cruise will not be permissible due to the problems it could create in aircraft traffic control.

Figure 2b shows the effect of change in ~~increasing~~ atmospheric temperature from ~~above~~ standard for a constant altitude cruise and a constant weight. The airplane velocity increases with an increase in temperature since the speed of sound increases and the Mach number is held constant. The drag remains nearly constant for all temperatures and the slight rise is due to a small increase in the dynamic pressure. Again the thrust must follow the drag for level unaccelerated flight and this involves a throttle increase as the temperature rises. If the throttle were ~~was~~ allowed to remain in one position the engine thrust would fall off with increased temperature and the aircraft would not maintain altitude or speed. The engine specific fuel consumption increases with atmospheric temperature and this indicates that a hot day cruise isn't as efficient as that of a standard day. Since the weight and thus the lift are assumed constant and the drag is essentially constant over the temperature range considered, little or no change in the L/D would occur as shown. The effects of increased atmospheric temperature on the performance parameters during the climb and acceleration segment of the mission would be of similar nature with the following exception. As previously stated, the throttle setting is held constant for most of the climb, and an increase in temperature would cause a reduction in thrust and fuel flow rate. Although the SFC increases with temperature, the reduction in thrust is more predominate, resulting in the reduced fuel flow rate as the temperature is increased.

The foregoing discussion is intended to be an aid in understanding the effects described in the remaining parts of the paper. It considered only instantaneous points along the flight profile and the actual problem is of a more complex nature, as the conditions discussed are all interrelated and occur throughout the entire mission. It should be reemphasized that the altitude and temperature effects discussed would apply generally to ~~other~~ any supersonic transport configurations with similar engines.

EFFECTS OF ATMOSPHERIC TEMPERATURE VARIATIONS ON AIRPLANE DESIGN

It is important for the airplane designer to have an understanding of the effects of atmospheric temperature variations on the aircraft performance in the early design stages. Using information on expected temperature extremes, he must determine the value of the various airplane design parameters which would give the best overall performance for the entire temperature range considered. Figure 3 illustrates how the designer must account for the effects of atmospheric temperature variations in the design phase in establishing two important aircraft design parameters, wing loading ($\frac{Wg}{S}$) and thrust-to-weight ratio ($\frac{T}{Wg}$) . This figure shows the variation of relative payload with thrust-to-weight ratio and wing loading for a 3200 nautical mile design mission using a Mach 3 Breguet cruise. Curves for a standard day and for a plus and minus 20^{o}F day experienced throughout the complete climb and cruise portion of the flight profile are shown. A brief description of the parameters involved should prove helpful in understanding the trends shown in the figure. New Paragraph

The airplane thrust-to-weight ratio or engine sizing parameter is defined as the standard day maximum sea level static thrust for all four engines divided by the airplane take-off gross weight. As the thrust-to-weight ratio increases, the engine size would have to increase (gross weight being constant) as would the engine pod weight and the overall drag of the airplane. The wing loading or wing sizing parameter is defined as the airplane take-off gross weight divided by the wing area. Since the gross weight was held constant, the wing loading was changed by varying the wing area, and the attendant effects on structural weight and on drag were accounted for. Thus an increasing wing loading indicates a decreasing wing area. It is obvious, then, that thrust-to-weight ratio and wing loading define engine and wing size respectively. Because of certain assumptions pertaining to the structural and equipment weights, the absolute magnitude of the payloads cannot be considered as definitive. Thus the resultant payloads are presented in figure 3 relative to the maximum payload obtained on a standard day. For the purposes of this paper, then, trends rather than absolute values are of prime importance and these are shown adequately by considering the relative values and their variations with wing loading and thrust-to-weight ratio.

The solid curve of figure 3a shows the variation of relative payload with thrust-to-weight ratio for a standard day and a wing loading of 80 pounds per square foot. A thrust-to-weight ratio of about .43 is shown to give the maximum payload for this case. It should be pointed out that the actual value of thrust-to-weight ratio indicated as optimum will vary with the engine cycle and flight profile considered. The loss in payload for thrust-to-weight ratios higher than optimum is due to the attendant increased engine and nacelle weights. This points out the penalty involved in using a conservative design approach by oversizing the engines to account for any uncertainties in the airplane drag or engine thrust. The reduction in payload for thrust-to-weight ratios lower than optimum is a result of the excess time spent in acceleration where the fuel flow rates are high. The dashed curves show the variation of relative payload with thrust-to-weight ratio for ~~[illegible]~~ atmospheric temperatures of plus and minus 20°F from standard. Some variation in the optimum thrust-to-weight ratio for a change in temperature is indicated. The results also show a large variation in performance associated with a 20°F change in the atmospheric temperature. For the optimum conditions, this effect amounts to a loss of about 25 percent of the standard day payload on a 20°F hot day or about the weight of 32 passengers and baggage. Figure 3b shows the variation of relative payload with wing loading for standard and nonstandard temperatures and for a thrust-to-weight of .45 . No change in the optimum wing loading with a temperature change is indicated, but again the large payload losses on a hot day and gains on a cold day are evident.

One reason for the large performance gains and losses of figure 3 is seen by considering the changes in the transonic acceleration values as a result of nonstandard temperatures. Figure 4 shows the variation of minimum acceleration rates (occurring in this case at a Mach number of about 1.1) with thrust-to-weight ratio and atmospheric temperature. The wing loading of 80 pounds per square foot and the maximum throttle setting were both held constant. The optimum thrust-to-weight ratios from figure 3 are indicated by the circles on the corresponding curves of figure 4, and it can be seen that these occur at the same level of acceleration. The results indicate very low values of minimum acceleration for optimum or near optimum thrust-to-weight ratios. This is due to the relatively high altitudes and accompanying low thrust levels which are necessitated by sonic overpressure limitations and reflected in the flight profile assumed. Considering a thrust-to-weight ratio of .45 , it can be seen that the standard day minimum acceleration of [illegible] is reduced about 23 percent as a result of a 20°F increase in atmospheric temperature. This acceleration loss is due to thrust degradation with temperature and results in longer times spent in the high fuel consumption acceleration phase, producing a loss in payload capability. A decrease in temperature below standard increases the acceleration level, decreases the time required for acceleration, and thus results in increased payload capability. As figure 4 shows, an airplane designed for an optimum thrust-to-weight ratio with respect to payload capability on a standard day will still have positive acceleration capability on a 20°F hot day but would suffer a large reduction in payload capability as previously indicated.

The airplane designer would employ a procedure similar to that described to determine any effects on design wing loading or thrust-to-weight ratio as a result of nonstandard temperatures. Of course, there are other areas to consider in the design phase, such as take-off and sonic boom effects, where increased atmospheric temperatures may have a bearing on the selection of the wing and engine size. However, for the conditions considered, it appears that changes in atmospheric temperature have little or no effect on the optimum wing loading and a small effect on the optimum thrust-to-weight ratio as determined on a standard day. This indicates, then, that the designer will need to consider only the approximate maximum temperature extremes in which the airplane can be expected to operate and thus a close definition of these temperatures will not be required from the meteorologist at an early date. The results do show that temperature variations will play an extremely important role in the operation of the supersonic transport due to the large reductions in performance on a hot day. For use in the remainder of this paper, a wing loading [illegible] pounds per square foot and a thrust-to-weight ratio of .45 have been selected as a result of this study. Also, only hot day conditions will be considered hereafter due to the actual improvements in performance as a result of atmospheric temperatures below standard.

EFFECTS OF INCREASED ATMOSPHERIC TEMPERATURE DURING VARIOUS PHASES OF THE FLIGHT

The preceding discussion has shown that the Supersonic Transport experiences severe losses in performance as a result of operation on a hot day. The operators of the aircraft must cope with these effects as they have with similar effects, although less severe, in past generations of transport aircraft. For the [redacted] Meteorologist, then, it is well to examine these effects on the operation of the supersonic transport to determine what if any improved weather information will be required by the airline operators. Thus the effects of variations in atmospheric temperature in each phase of the supersonic transport mission will be considered.

Climb and Cruise. - Because the preceding study was based on constant temperature increments throughout the climb and cruise portions, the magnitude of the performance losses in each segment of the flight profile due to hot day operation was not apparent. Further clarification of the picture may be obtained by reference to figure 5 which shows the variation of fuel used with atmospheric temperature for various segments of the mission profile. As indicated in the insert [redacted], the flight profile was divided into four segments for this study. Segment number one covers the subsonic acceleration and climb to 25,000 feet, and segment two includes the climb and transonic acceleration to a Mach number of 2. Segment number three consists of the acceleration to Mach number 3 and climb to cruise altitude. The Mach 3 Breguet cruise is labeled segment number four. Deceleration and letdown at end of cruise is not included in this study since the weight of fuel is quite small and the temperature effects unimportant. A given temperature increment above standard was then applied to each segment independently and the mission was flown using standard day temperatures throughout the remaining parts of the flight profile. The total fuel consumed for the climb and cruise segments was then compared to that of a flight having standard day temperatures throughout. The resulting percent increase in fuel used above standard was plotted against the corresponding temperature increment for each segment as shown in figure 5. For example, considering a 20°F temperature increase in segment number two with standard temperatures over the rest of the flight profile, an increase in fuel used from standard of about 2.3 [redacted] percent is indicated. This amounts to about 4350 pounds of fuel consumed above the 189,800 pounds used to the end of cruise for the standard day mission. For reference purposes, the dashed curve of figure 5 shows the fuel used above that for a standard day as a result of the indicated temperature increments existing throughout the entire climb and cruise. It can be seen that increased temperatures in segments number 1 and 3 result in very little loss in the airplane's performance. The increases in fuel used are less than one-half of one percent on a 30° hot day. The cruising flight, or segment number 4, results in an increase in fuel used of about 1.35 percent for a 30° increase in temperature. The most critical portion of the flight profile is seen to be segment number 2 which includes the transonic acceleration. In fact, a temperature increase in this region results in a reduction in performance amounting to two-thirds of that caused by the same temperature increase existing over the entire flight profile. A temperature increment of plus 30° during segment number 2 amounts to a 4.13 percent or 7850 pounds increase in fuel used. This is a severe penalty when one considers that this represents the weight of about 37 passengers and baggage and results from a 30° temperature increase during a phase of the mission that covers only 198 nautical miles and which takes sixteen minutes to fly on a standard day. It is also interesting to note that the cruise phase, although taking 2627 nautical miles and 92 minutes on a standard day, indicates a penalty on a 30° hot day that is about one-third that of segment number 2. It is obvious then that atmospheric temperature variations will have a serious effect on the supersonic transport performance during transonic acceleration.

The results of this study indicate the importance of an accurate knowledge of the atmospheric temperatures along the mission profile. This information should be current and available to the airplane operators before the flight for the purpose of calculating payload and fuel required. Temperature measurements to at least 60,000 feet should be taken for about a 300 mile radius around the airport. Particular emphasis should be placed on the region of segment number 2 of the flight profile considered involving the transonic acceleration which occurs from about 25 to 200 nautical miles from the airport. In addition, it appears that temperature measurements will be required from 60,000 to 80,000 feet along the cruise path at intervals in range about equal to those presently employed across the United States. Additional studies will be needed to determine how frequently these temperature measurements will be required. However, due to the short flight times involved, it appears that the present twelve-hour interval between readings will be too great and that measurements will be needed perhaps as often as every hour, particularly in the region within 300 nautical miles of the terminals. It also appears that the accuracy of these temperature measurements might have to be improved over those presently taken, as a 5° increase along certain areas of the mission profile can lead to a considerable increase in fuel consumption.

It should be pointed out that the magnitude of the fuel losses shown in figure 5 would change when considering other profiles, ranges, aerodynamics and engines. However, it is felt that the characteristics of the above factors would not vary sufficiently from those used to change the relative importance of the fuel losses in the various profile segments.

Take-off and Landing. - Another area of concern to Supersonic Transport operation is the effect of increases in atmospheric temperature at the take-off and landing points. Elevated temperatures along the runway on take-off result in reduced thrusts and require increased take-off velocities for a given throttle setting to meet the climb-out conditions. As a consequence, the take-off distances become greater as the temperature is increased. Figure 6 shows the variation of the take-off distance with increases in temperature above standard on the runway. A take-off power setting, which due to noise considerations is somewhat less than maximum, was held constant. The percent increases in take-off distance shown are based on a standard day length of 6565 feet calculated for the aircraft considered in this paper, having a wing loading of 80 pounds per square foot and a maximum sea level static thrust-to-weight ratio of .45 . As indicated in figure 6, the take-off distance on a 30°F hot day reaches a value that is some 30 percent greater than the standard day length. Even so, this distance of about 8500 feet is well under the maximum allowable value of 10,500 feet. This is due to the fact that a relatively high thrust-to-weight ratio was found optimum for transonic acceleration at the high altitudes imposed by sonic boom requirements and as a result, fairly high thrusts are available for take-off. However, if these thrusts are much less than indicated, staying within the allowable take-off distance may become more of a problem on a hot day than is presented by the case considered.

Increases in atmospheric temperature during the landing phase of the mission have an effect similar to that experienced during take-off. Elevated temperatures result in higher landing speeds which in turn lead to longer landing runs. [redacted]

Descent and Reserves. - The descent portion of the supersonic transport mission will be similar to the climb phase in that a profile will have to be followed so as not to exceed 2 PSF overpressure on the ground. However, unlike the climb phase, a relatively small amount of fuel will be used for descent due to the very low power settings. For this reason it appears that increased atmospheric temperatures in this area will not be much of a problem as far as fuel economy is concerned.

In order to meet requirements for holding in a traffic pattern and travel to an alternate airport, the supersonic transport must have a certain amount of fuel in reserve at the end of the mission. These reserves based on current concepts amount to about 7 percent of the aircraft's take-off gross weight on a standard day. However, to perform the same requirements on a $30^{\circ}F$ hot day, the reserve fuel would have to be increased to about 7.5 or 8 percent of the take-off gross weight. Thus temperature information along the flight path and around the destination should be available prior to take-off in order to calculate the fuel needed to meet the reserve requirements.

This discussion has pointed out the penalties resulting from hot day operation in the various phases of the supersonic transport mission. It also has indicated the need for complete and accurate atmospheric temperature information along the flight profile and particularly in and around the terminal areas for preflight determination of the fuel and payload weights.

EFFECTS OF REGIONS OF HIGH TEMPERATURE ON TRANSPORT OPERATION

The performance losses in terms of excess fuel consumption associated with flying through regions of above standard atmospheric temperatures along certain parts of the mission profile have been shown. It may be possible to avoid these regions by course or altitude changes, assuming the operators have complete and accurate preflight temperature information. For this reason a few sample cases will be shown in which the flight profile was changed to avoid assumed discreet regions of elevated temperature in the climb and in the cruise phases of the mission. A mission typical of a great circle flight from New York to London of some 3000 nautical miles was considered. The same aircraft assumed for the previously discussed work, having a wing loading of 80 pounds per square foot and a thrust-to-weight ratio of .45 was employed. For purposes of simplifying the problem, a Mach 3 constant altitude cruise of 75,000 feet rather than a Breguet cruise was flown and this together with the shorter range results in the fuel consumed values being different from those of figure 5.

The first case examined considers one method of avoiding a high temperature region located in the transonic acceleration area of the profile as indicated by the shaded portion of figure 7. The 20°F above standard temperatures were assumed to occur from 25,000 to 52,000 feet corresponding to segment 2 of figure 5, and extend out along the course some 800 nautical miles. Standard day temperatures are assumed in all other areas. The transonic acceleration and climb of the standard 2 PSF overpressure profile, as indicated by the solid line, falls within the region of elevated temperature as shown. Flying this standard profile through the warm region results in a fuel usage at the end of cruise of 188,091 pounds or about 4025 pounds above the same mission flown on a standard day. The dashed lines represent a profile planned to avoid the elevated temperatures and follow standard conditions for the entire mission. The normal climb is followed up to 20,000 feet where the aircraft levels off and cruises subsonic at a Mach number of 0.8. Upon reaching a range of 800 nautical miles and having passed the high temperature region, the aircraft then follows a normal acceleration, climb and cruise. Following this profile results in 190,987 pounds of fuel being consumed at the end of cruise, or 2896 pounds more than the normal profile passing through the warm region. Thus it is seen that a further loss rather than a reduction in fuel usage occurs as a result of this type of diversion due to the off-design operation.

Any attempt to climb through and accelerate above the particular elevated temperature area of figure 7 would not be feasible because of the insufficient thrust available at the higher altitudes involved. If, however, the warm area had existed only below 25,000 feet, then only a small penalty would result from flying the normal mission through the area as was indicated by segment one of figure 5. It should be pointed out that this one example does not rule out other means of avoiding this region of elevated temperature and improving performance, say through course changes. In this case, however, if a course change results in an extension in excess of about 110 miles to the cruise phase for the aircraft considered, this too will not provide any advantage over following a normal flight profile through the warm region.

Another problem area that might be mentioned in connection with figure 7 is that of supersonic transport navigation. The high speeds producing rapid changes in position will make navigation and traffic control increasingly difficult, but it will be mandatory that the location of the aircraft be known at all times. Complicating this task is the fact that variable meteorological conditions can have a definite effect on the aircraft's progress along the flight path. Deviations in atmospheric temperature from standard, for example, can affect the transport's ability to meet a given fix, that is, arriving at an assigned altitude at a given time and range. To illustrate this, consider the normal flight path of figure 7 passing through the 20°F above standard region as compared to the same mission on a standard day. Because of the additional time required to complete the transonic acceleration phase of the mission due to the elevated temperatures, the aircraft would arrive at its assigned cruise altitude some

5.5 minutes later and 74 nautical mi[illegible] than the same aircraft flown on a standard day. An increased rate of climb to offset this deviation would result in further increases in fuel consumption during this phase of the flight. However, with a complete and accurate knowledge of the existing temperatures along the flight profile, the operators can predict these changes in the navigation fix prior to the flight.

Two examples of attempts to avoid areas of increased temperature during the cruise phase of the mission by changes in altitude are illustrated in figure 8. Shown in figure 8a is a plus 20°F temperature region covering 1500 nautical miles of the 75,000 foot altitude cruise path. Flying through this region results in 1[illegible]5,169 pounds of fuel being used to the end of cruise or 1103 pounds above the same mission flown on a standard day. Lowering the cruise altitude to 70,000 feet where standard day temperatures exist shows an improvement in fuel consumption of 1445 pounds compared to flying through the warm area at 75,000 feet. It is interesting to note that the resulting fuel consumption is about the same as that used for the standard day mission at 75,000 feet, [redacted] However, raising the cruise altitude from 75000 to 80000 feet to avoid increased [redacted] temperatures would result in a large penalty in this case. [redacted]

Figure 8b shows the same elevated temperature region extending to a lower altitude. In this case, in order to avoid the elevated temperatures, the aircraft would have to cruise at 65,000 feet and would use 189,803 pounds of fuel at the end of cruise. Thus it would have been better by some 4634 pounds to have cruised through the warm region at 75,000 feet. These two examples indicate that if the region of increased temperature is such that a small lowering of the cruise altitude to cooler conditions is possible, then a gain in performance will result. However, if this required change in altitude is very much, as for example from 75000 to ~~[illegible]~~ 65000 feet ~~80,000 feet in this case~~, large amounts of excess fuel will be expended as figure 8b indicates. [redacted]

Another means of avoiding regions of elevated temperatures in the cruise phase is to alter the course laterally as illustrated in figure 9. Here the trip range is plotted against lateral range and the scale of the latter has been expanded for clarity. The purpose will be to determine the lateral displacement of another course for standard day temperatures at the same altitude as a result of using the same amount of fuel as would be consumed in flying through a given area of elevated temperature. Figure 9a shows a plus 20°F above standard temperature region covering the entire 75,000 foot cruise phase of the mission. Flying through this region results in the use of 185,757 pounds of fuel at the end of cruise, or about 1691 pounds more than the same flight on a standard day. Now by using this same amount of fuel and altering the course upon take-off, a maximum lateral flight path displacement of about 114 nautical miles is possible under standard temperature conditions. This, of course, is due to the fact that using the same amount of fuel it is possible to fly farther on a standard day than on a hot day. Thus for this case, in order to obtain any significant improvements in performance over flying through the warm region, the lateral distance would have to be much less than the maximum of 114 nautical miles. Of course, any increase in this distance would result in more fuel being consumed than the 185,757 pounds used flying through the warm area. Figure 9b shows an increased temperature region covering 1500 nautical miles of the cruise phase. This is the same area used in figure 8 and, as indicated, 185,169 pounds of fuel are consumed to the end of cruise. Again, using this same amount of fuel, a maximum lateral course displacement of about 92 nautical miles is possible when flying standard day conditions. The results of these two examples show that unless standard or colder than standard temperatures can be reached in a very small lateral distance, little or no improvements in performance can be expected over flying through warm regions on the normal flight path.

It should be pointed out that the last three figures have only illustrated a few examples of supersonic transport operation. However, the results give a good indication of what is involved in attempting to improve performance by avoiding regions of higher than standard atmospheric temperature. Regardless of what course or flight path is followed, the operators will have to have a current knowledge of the temperatures along the route for navigational purposes and in order to predict the aircraft's performance in terms of fuel required.

CONCLUDING REMARKS

From this examination of the effects of atmospheric temperature on supersonic transport performance, several points of interest have evolved. It appears, from a designer's standpoint, that nonstandard temperatures will not have a great effect on the airplane design parameters which have been considered. However, as a result of consideration of hot day operation, severe reductions in performance are indicated with the greatest portion of the losses occurring in the transonic region. Increased temperatures at the terminal areas will result in longer take-off and landing distances, but these were found to be within the maximum limits for the configuration considered. Higher than standard temperatures in the region of the destination will demand increases in the reserve fuel supply to meet the refused landing and holding requirements. The few cases considered show that altering the mission profile to avoid elevated temperatures and thereby attempting to improve performance will probably not be a worthwhile procedure. It was pointed out that the varying times and altitudes over a navigation fix as a result of nonstandard temperatures along the flight path will present problems in both navigation and traffic control for this type of transport aircraft.

This has been only a brief investigation into the effects of atmospheric temperature which is but one of the meteorological factors to consider in the design and operation of the supersonic transport. [redacted] Based on the results of this study, it appears that performance losses associated with hot day conditions will be of a greater consequence to the operator than for current subsonic jet transport aircraft. Because of the severe losses in performance as a result of increased temperatures during certain phases of the mission, the operators will need more frequent and accurate temperature information than that which is supplied today, particularly in and around the terminal areas.

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DRAFT

CLIMB PROFILE

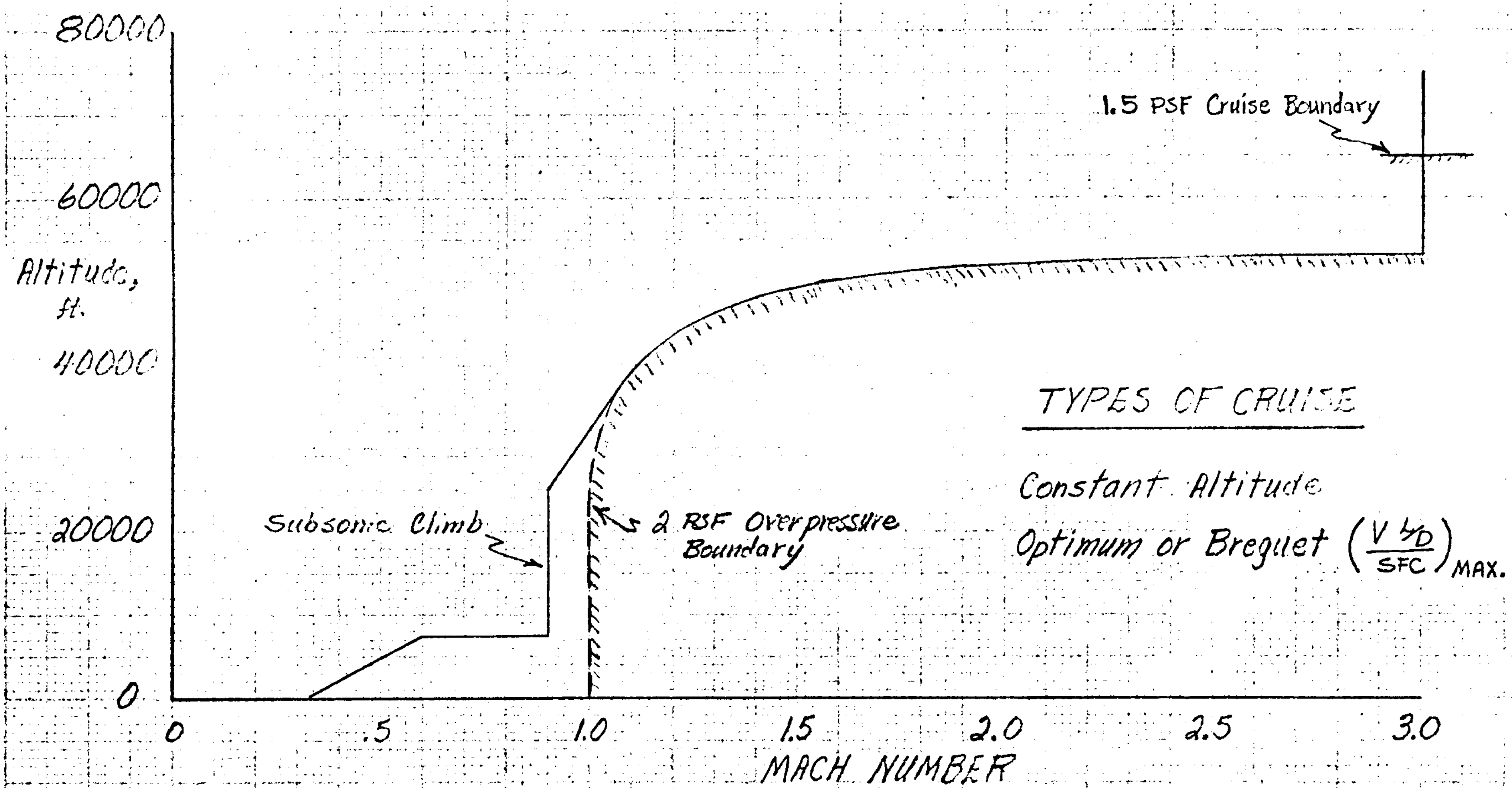
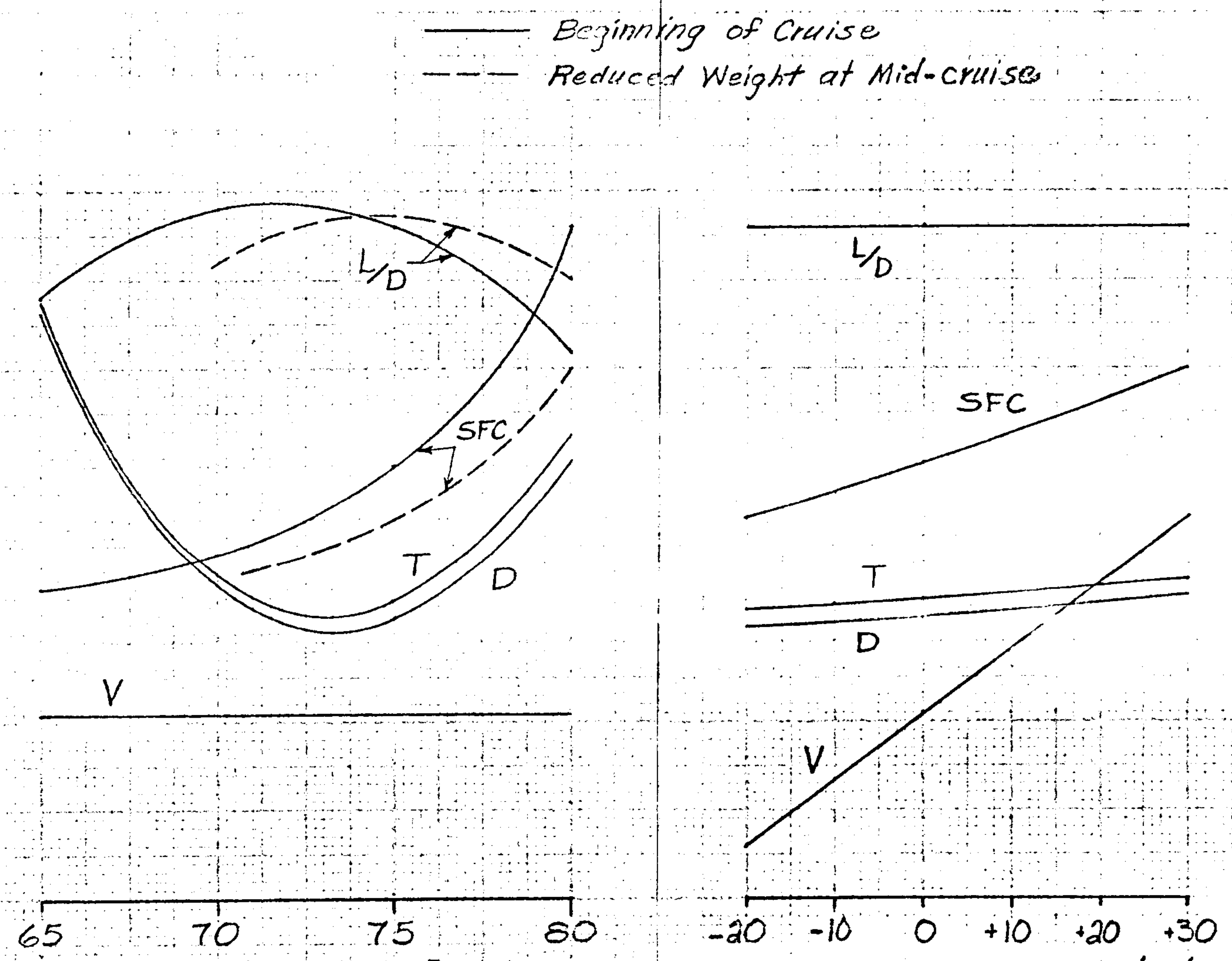


Fig. 1

ALTITUDE AND TEMPERATURE EFFECTS

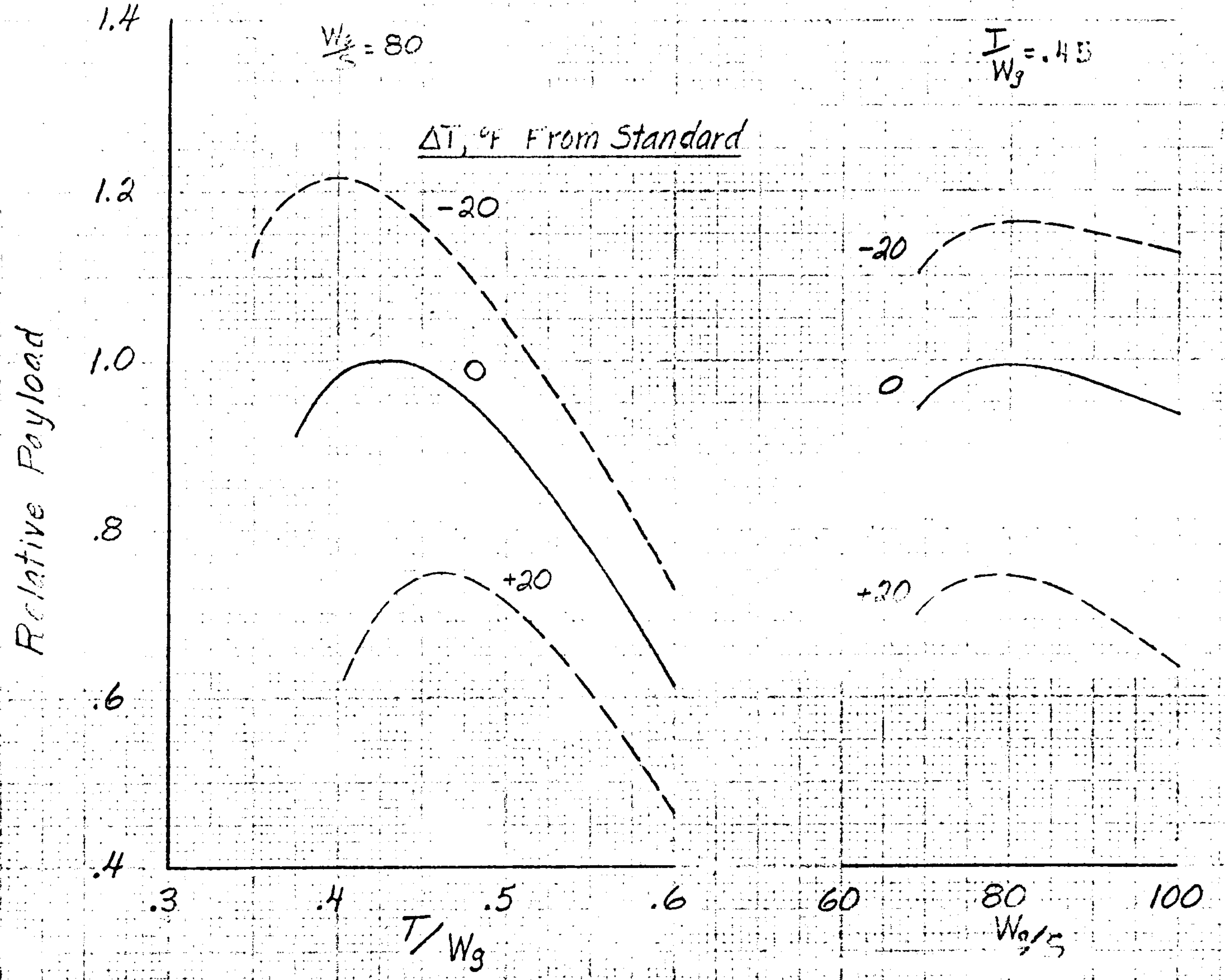


(a) Effect of Altitude at Standard Temperature

(b) Effect of Temperature at Constant Altitude (75000 ft.)

Fig. 2

AIRPLANE DESIGN PARAMETERS



(a) Thrust-to-Weight Ratio

(b) Wing Loading

Fig. 3

TRANSONIC ACCELERATION CHARACTERISTICS

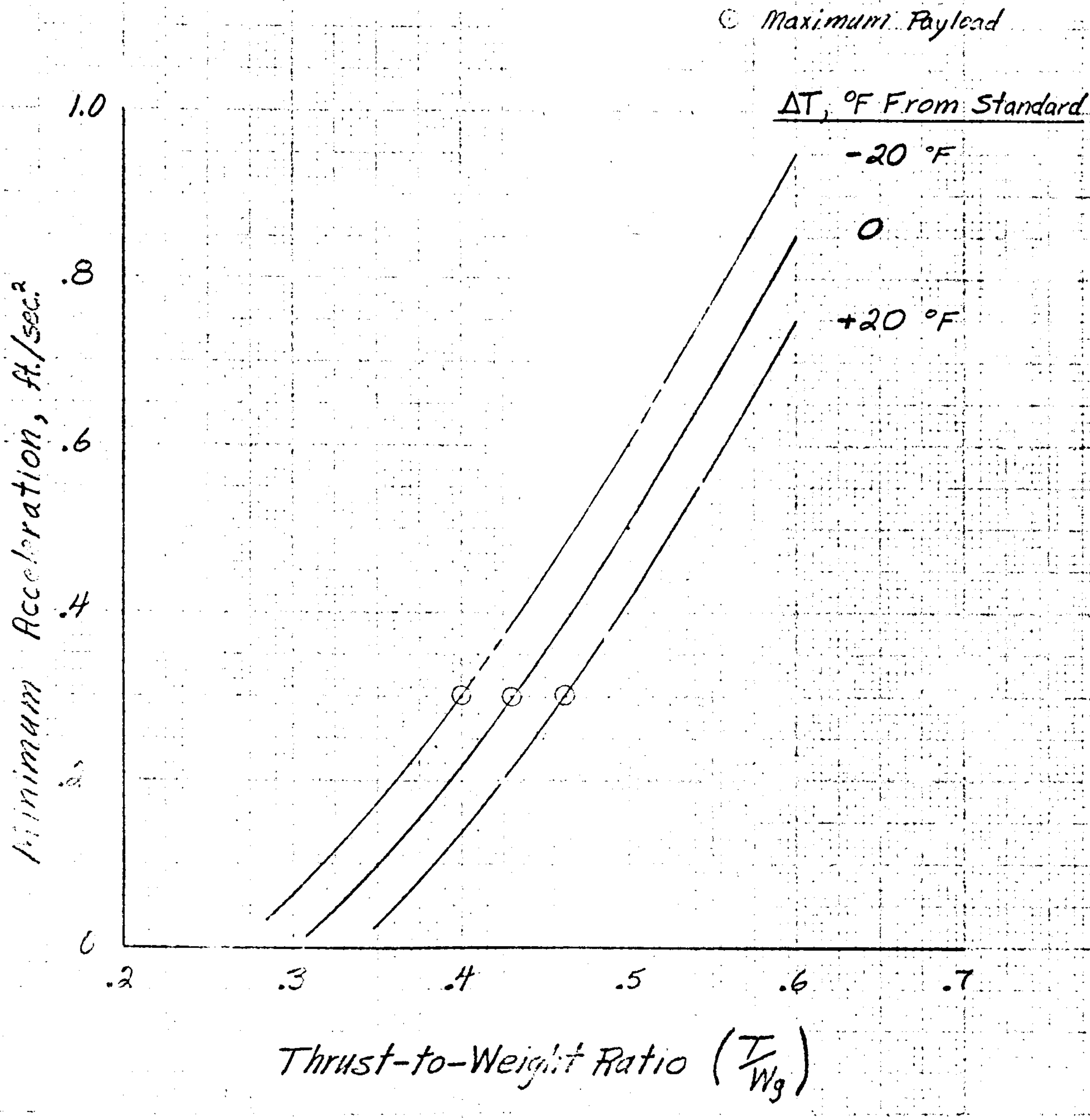


Fig. 4

EFFECTS OF TEMPERATURE ON FUEL CONSUMPTION

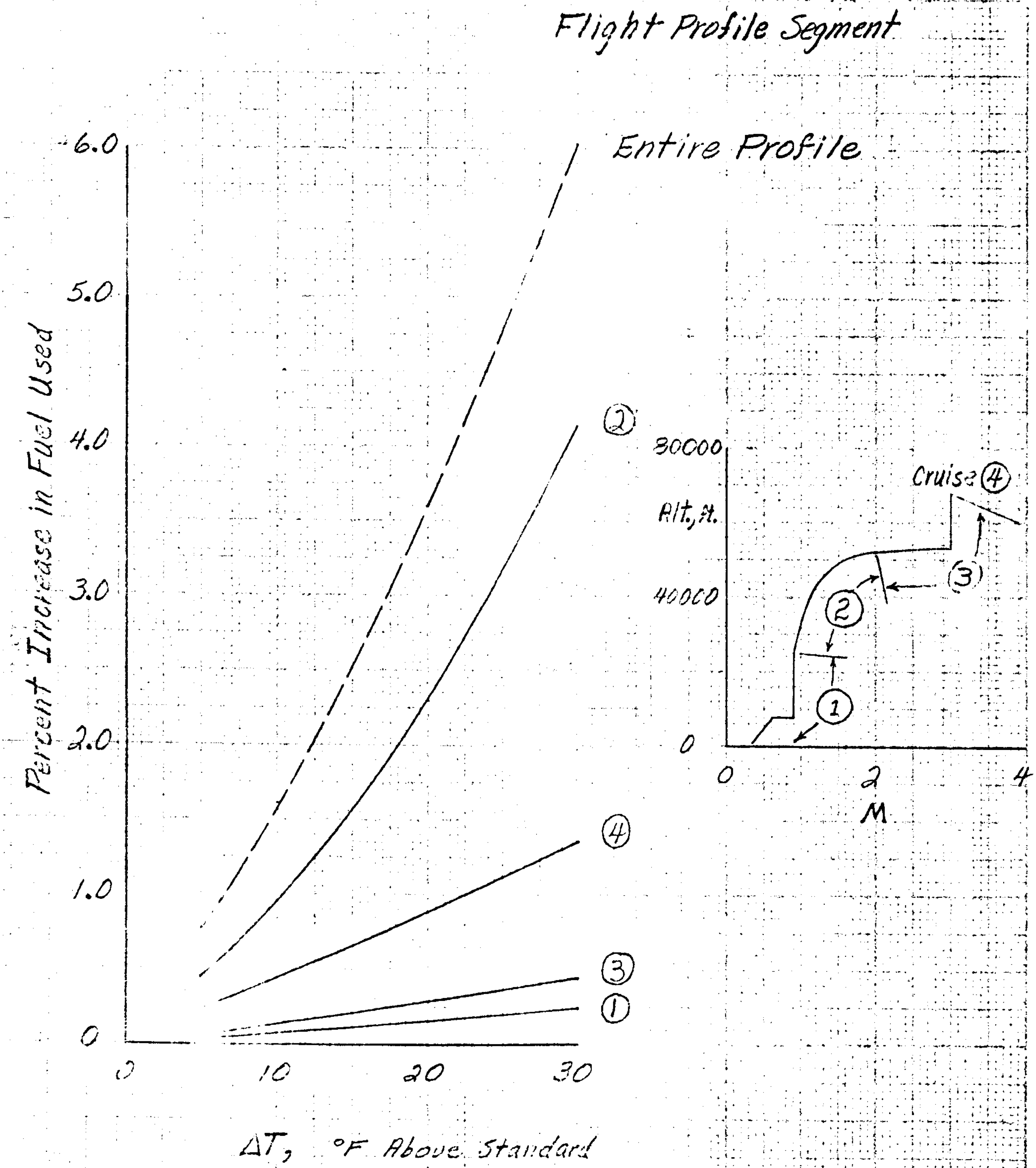


Fig. 5

EFFECT OF TEMPERATURE ON TAKE-OFF

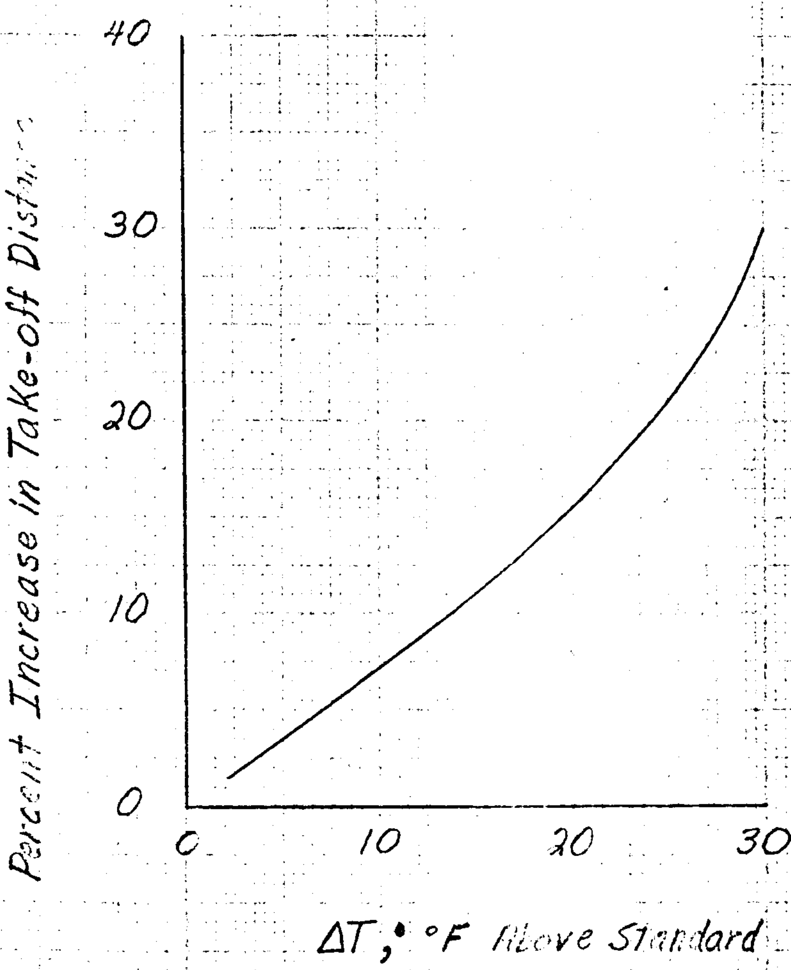


Fig. 6

ALTERNATE CLIMB-OUT FOR TEMPERATURE AVOIDANCE

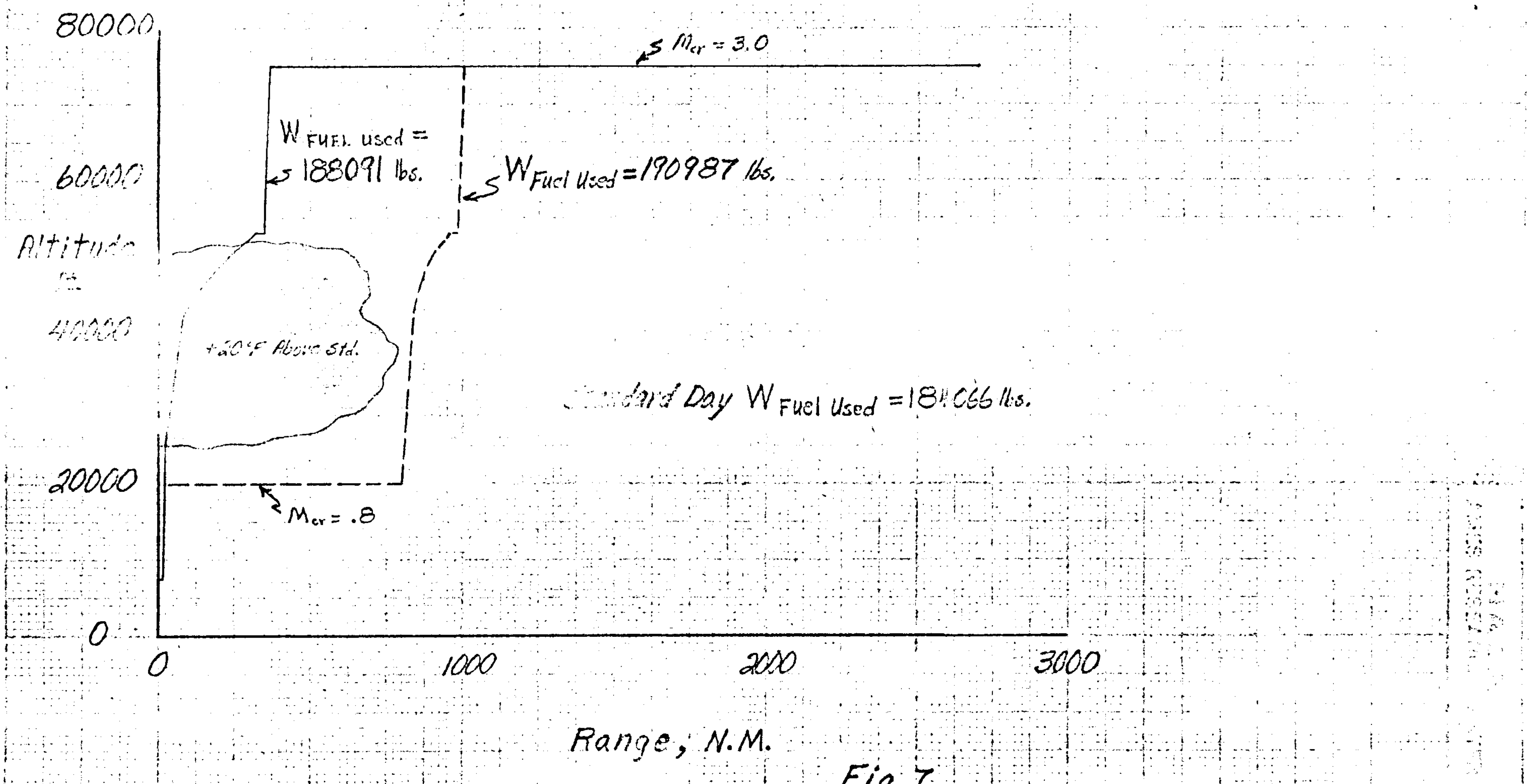


Fig. 7

ALTERNATE ALTITUDE FOR TEMPERATURE AVOIDANCE

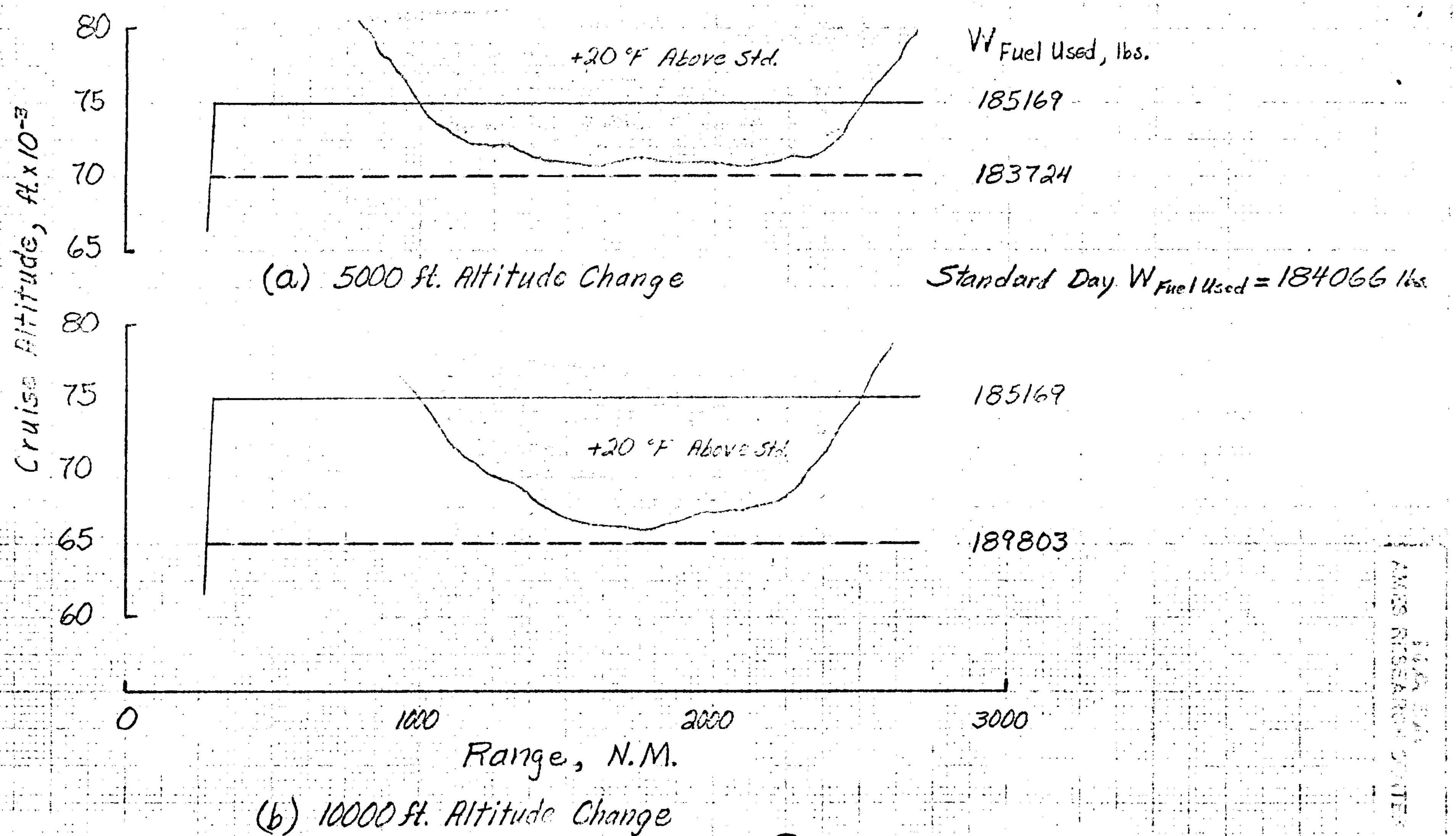


Fig. 8

ALTERNATE COURSE FOR TEMPERATURE AVOIDANCE

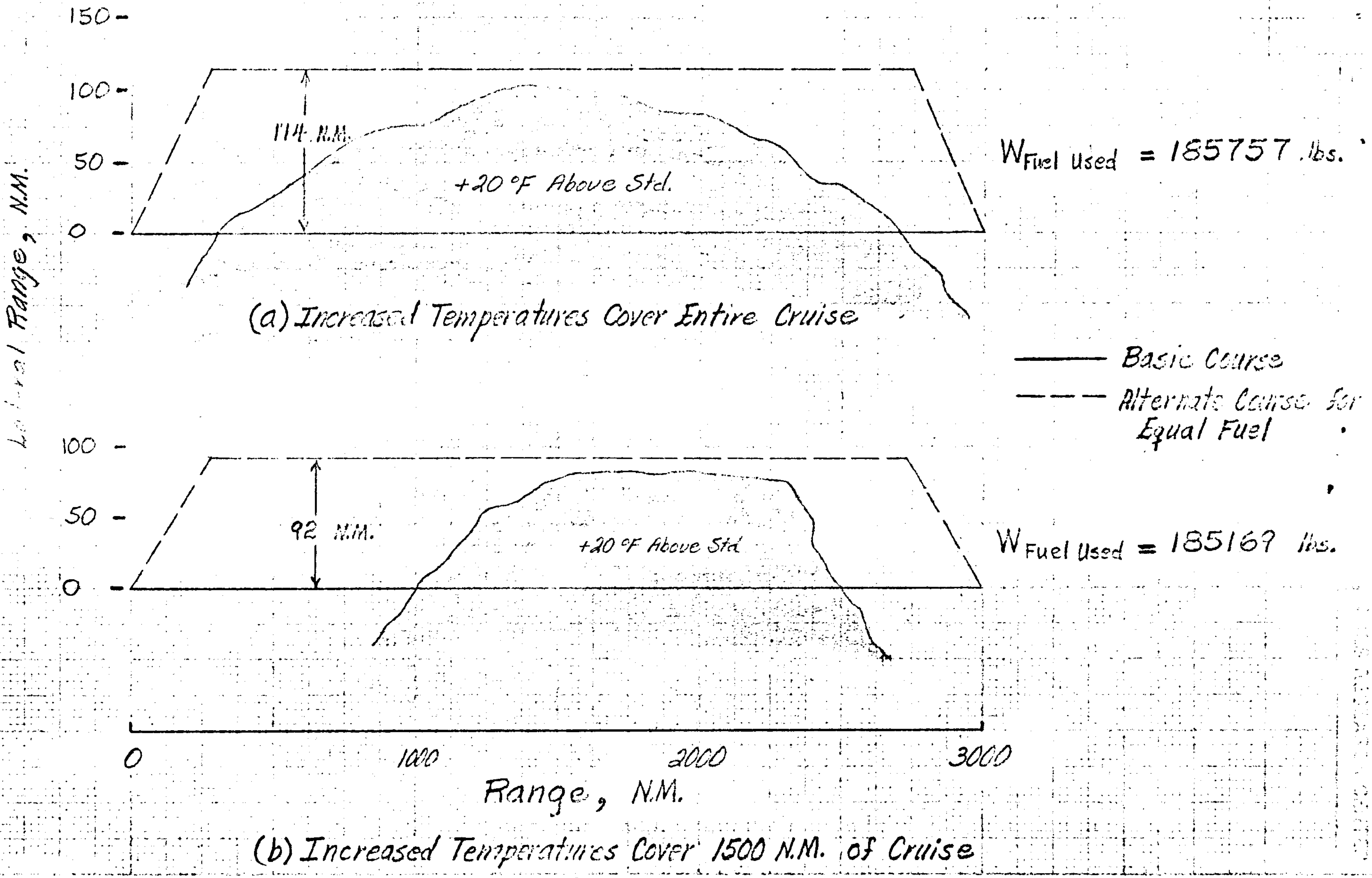


Fig. 9